E298A/EE290B – Projects and Systems

- Project Proposal due Tuesday February 15th
- Project review session Thursday February 10th instead of Lab.
  - Review times will be scheduled to avoid waiting
  - Review will be in Building 2 at LBL
    - Erik's office is 2-454
    - Alex's office is 2-419
- No problem set this week. Project preparation and proposal writing instead.

Project Guidelines I

- A project is required for the class and is expected to be a substantial part of the learning experience. The scope of the project should be realistic and take into account the limitations in time and materials. The project should explore a scientific application where electron beam lithography is need to achieve a result, or the electron beam lithographic process itself. The project will consist of a written proposal, which must describe the planned experiments together with a suitable schedule. The proposals will be reviewed to make sure that the scope is appropriate. The project milestones are expected to be followed. A written report of the project results and a formal presentation to the class are required.
- Proposals due Tuesday, February 15th
- The report is due Tuesday, May 3th
  - The report should be formatted in the style of a JVST paper, 4-6 pages in length. Each journal page is approx. 900 words, and each figure is equivalent to 200 words
- Class presentations will be on May 5th, which will be the last day of class. Each presentation will be 15 minutes long in the style of a conference talk.
  - Allow 1 minute per viewgraph

Project Guidelines II

- The work at LBL will be under the supervision of E.H. Anderson, J.A. Liddle or Josie Lee.
- The project can be related to the thesis work of the student, but should not be in the critical path!
- The project should use readily available materials and processes to the fullest extent possible. Health and safety issues may restrict materials and processes – investigate these possibilities early
- Samples for e-beam lithography can be on 3 – 8” wafers and quartz plates. No fragments!
- Data sets can be generated at LBL or with any CAD system that produces a suitable GDSII file
- Start prototyping and process development early!

Project Hints

- The voice of experience….
  - How hard could it be….?
  - What could possibly go wrong….?
- Keep the project scope simple, focused and reasonable. Estimate what you think you can do, and divide by two, focusing on the critical elements. This is a class project and not a thesis!
- Start early! Experimental efforts always take longer than expected, even when you know that experimental efforts always take longer than expected (yes, this is recursive!). Lots of things can go wrong in the lab, and often do. Remember, if you can't imagine how something could fail, it just shows a lack of imagination!
- Don't reinvent the wheel – if someone has already gone to the trouble of developing a process, use it!
- The written proposal is only a plan and <u>*"no plan survives contact with the enemy"*</u>. Be prepared to update your plan in light of experience.

Project Proposals Due Next Tuesday!!

The Plan

Task1 xxxxxxxxxxxxx

Task2 xxxxxxxxxxxxx

Task3 xxxxxxxxxxxx

Task4 xxxxxX

Report xxxxxxxxxxX

Presentation xxxX

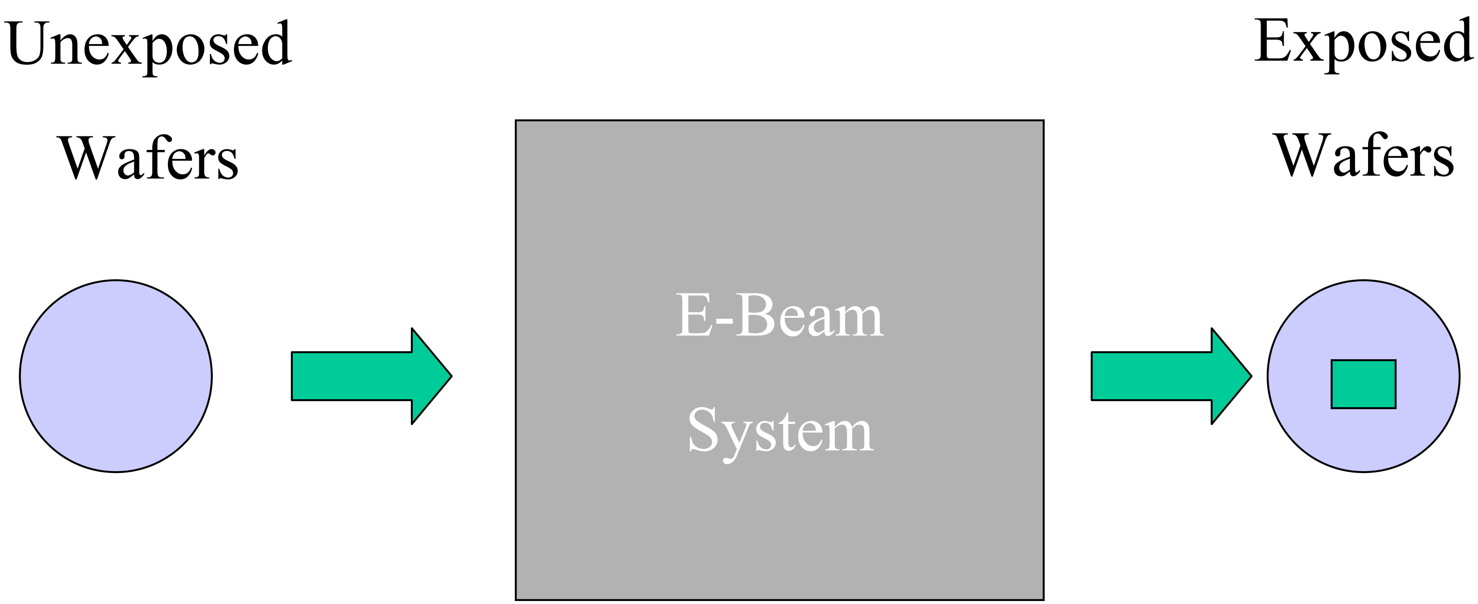
What really happens

Task1	xxxxxxxxxxxx (procrastinate)
Task2	xxxxxxxxxxxx (problems)
Task3	xxxxxxxxxxx (equipment down)
Task4	xxxxX (luck)
Panic	xxxxxxxxxxxxxxxxx
Report	xX
Presentation	xxxX

E298A/EE290B – E-Beam System Issues

- Purpose: To Understand System Level Issues
  - Historical Evolution
  - Beam Deflection – Vector Scan, Shape beam, Raster Scan
  - System components
  - Example of LBNL Nanowriter

Top Level of E-Beam System Architecture



Top Level of E-Beam System Architecture

High Level Specifications

E-Beam System

- Resolution – Process
- Throughput
- Placement Accuracy
- Exposure Area
- Cost
- Sample Size

Top Level of E-Beam System Architecture

Resolution

Resolution depends on the E-Beam System **and the process**

- E-Beam System
  - Beam size, beam stability, mechanical stability
  - Beam operating voltage
  - Detectors/Algorithms for Focus and Stigmation
  - Ability to maintain Focus/Stigmation within the exposure area
- Resist and Processing
  - Intrinsic resist properties and Mechanical properties

Top Level of E-Beam System Architecture

Throughput

- Resist Sensitivity [μC/cm^2] *KRS=30, PMMA=700, HSQ=1000*
- Beam Current *(400-500pA normal, 10nA available)*
- Stage motion *(2 sec small move)*
- Pattern generator Overheads
  - Digital to Analog Converter (DAC) settling Time
  - Shape computation overhead *(highest for many small shapes)*
  - Data flow i.e. hard-drive *(highest for many small shapes)*

Top Level of E-Beam System Architecture

Resist Sensitivity

Resist	Uses	Tone Sensitivity	Dense Iso	Advantage	Disadvantage
KRS (IBM)	KZP Masks	P 30 μC/cm²	60nm 40nm	Fast, stable No PEB	Acid etch resistance
PMMA	Liftoff	P 700 μC/cm²	40nm 20nm	Good resolution	Slow, outgassing, metrology difficult
SAL601 AZpn114	Device	N 100 μC/cm²	80nm 35nm	Fast, good etch resistance	Modest resolution
Calixarene	Zone Plates	N 20,000 μC/cm²	25nm 10nm	Ultra-high resolution	Very Very Slow Supply QC
HSQ Bi-layer	Multi-Purpose	N 1000 μC/cm²	30nm 15nm	High-resolution Etch resistance	ICP etch required Modest speed

Top Level of E-Beam System Architecture

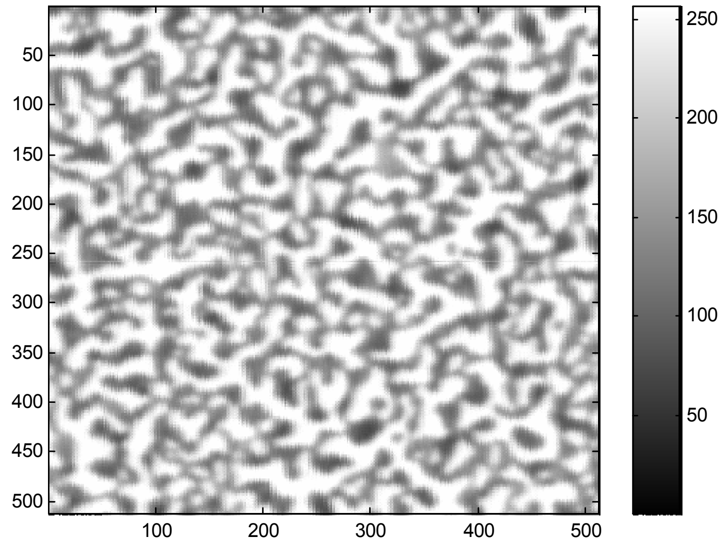
Placement Accuracy

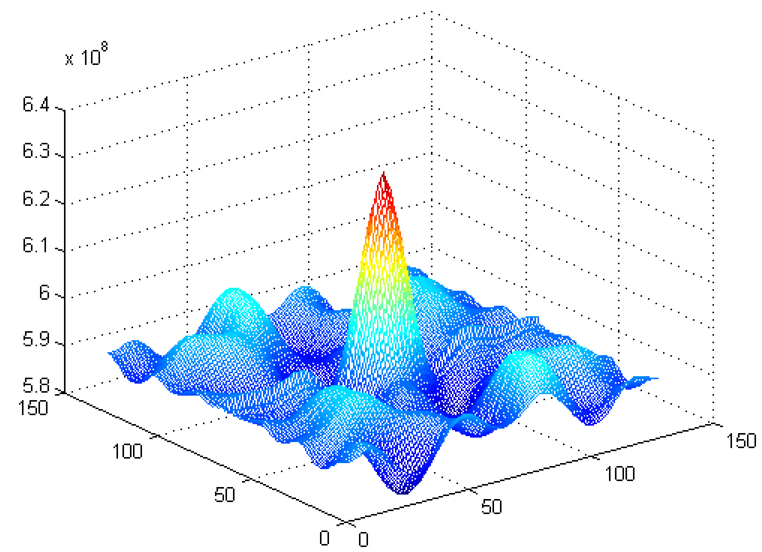
Fundamentally depends on system stability, repeatability, and calibration techniques.

- Almost all repeatable and measurable errors can be eliminated with proper calibration. “The accuracy is in the software” Peter Crawley Past Director of Leica Lithography
- Error numbers are usually mean + 3σ
- Stitching errors
- Absolute Placement (vs IPRO, LMS20/20)
- Overlay (wafer to wafer or mask to mask)

Top Level of E-Beam System Architecture

On Axis Calibration of the Nanowriter





High Spatial Frequency
Gold Island Sample

Auto-correlation for
Focus and Stigmation

System Architecture Historical Evolution

Modified SEMs and PMMA 1970s

"Flying Spot Scanner" Pattern Generator

PMMA was a "breakthrough" for e-beam lithography

- Good resolution
- Poor sensitivity
- Poor etch resistance
- Good for liftoff

M. Hatzakis, "Electron resists for microcircuit and mask production," J. Electrochem. Soc. 116, 1033-1037 (1969).

System Architecture Historical Evolution

IBM VS-6 ≈ 1989

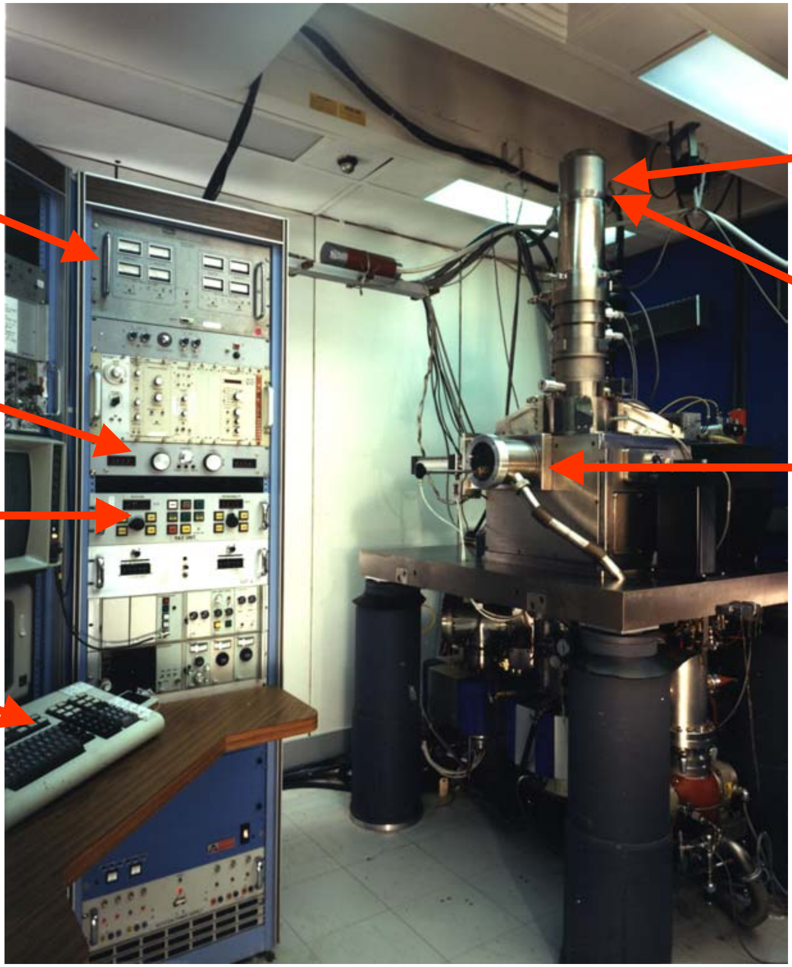
Deflection Amp

Rotation Correction

Alignment

Computer

IBM Series 1



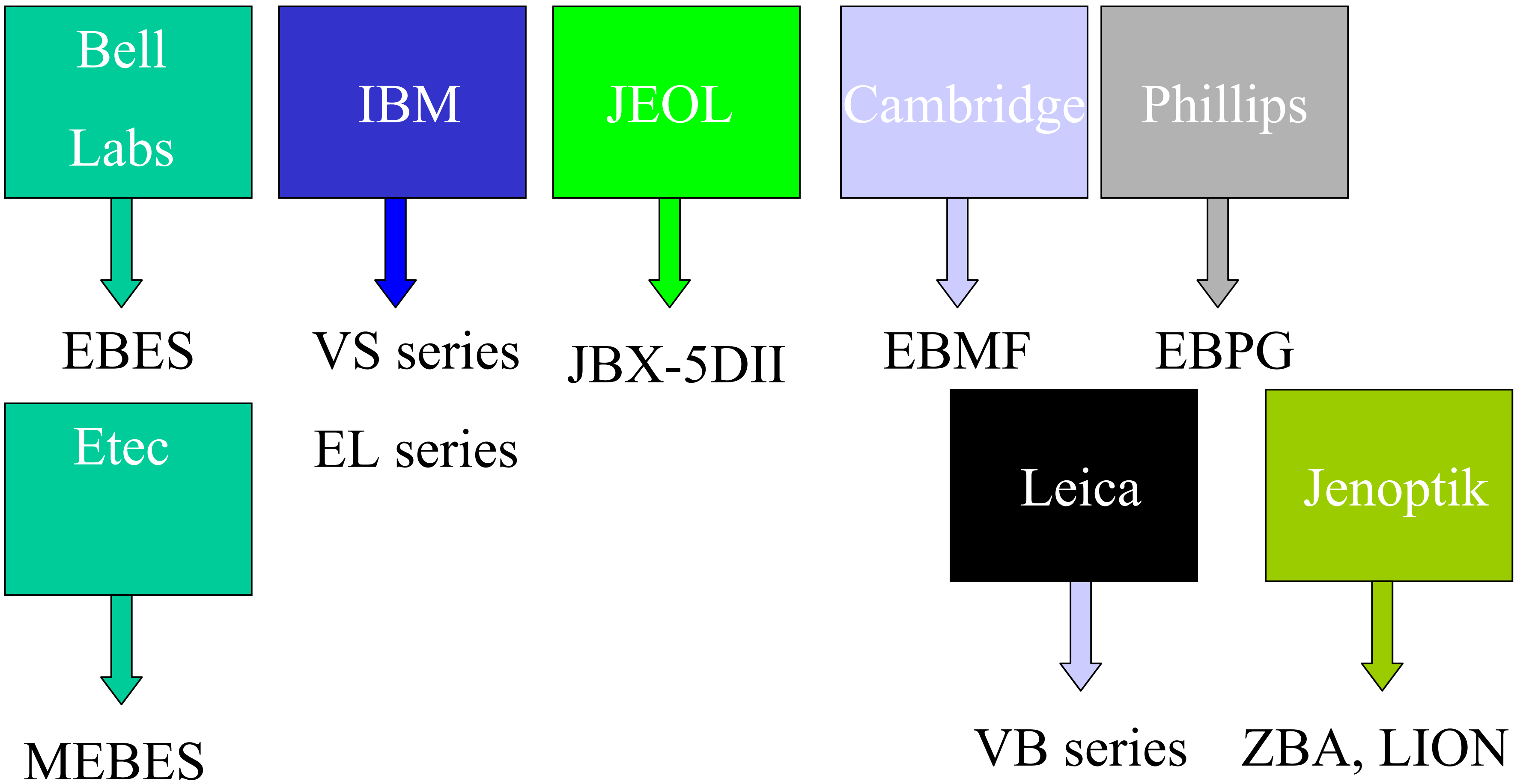
LaB_6 Source

50KV

Manual Load

System Architecture Historical Evolution

Dedicated E-Beam Systems



Beam Deflection - Raster

- Raster beam, also called Gaussian beam.
- Example Etec MEBES – Mask making.
- Beam moves in a periodic pattern like a TV display. The beam is blanked on and off to produce the pattern.
- Advantages: Fast, Non-linear effects can be corrected, Quasi one dimensional deflection and periodic signal simplifies electronics.
- Disadvantages: Difficult for dose control, sparse patterns require longer exposures.

Beam Deflection – Shaped Beam

Shaped beam, also called vector (by Etec)

- Example IBM EL4, ZBA 320 – Mask Making and ASIC.
- Beam is deflected over a set of apertures to form a basic shape such as a rectangle and then de-magnified by the final lens.
- Advantages: Speed, entire shapes are flashed at once.
- Disadvantages: Complexity, several additional deflection and shaping components are required.

Beam Deflection – Vector

Vector beam,

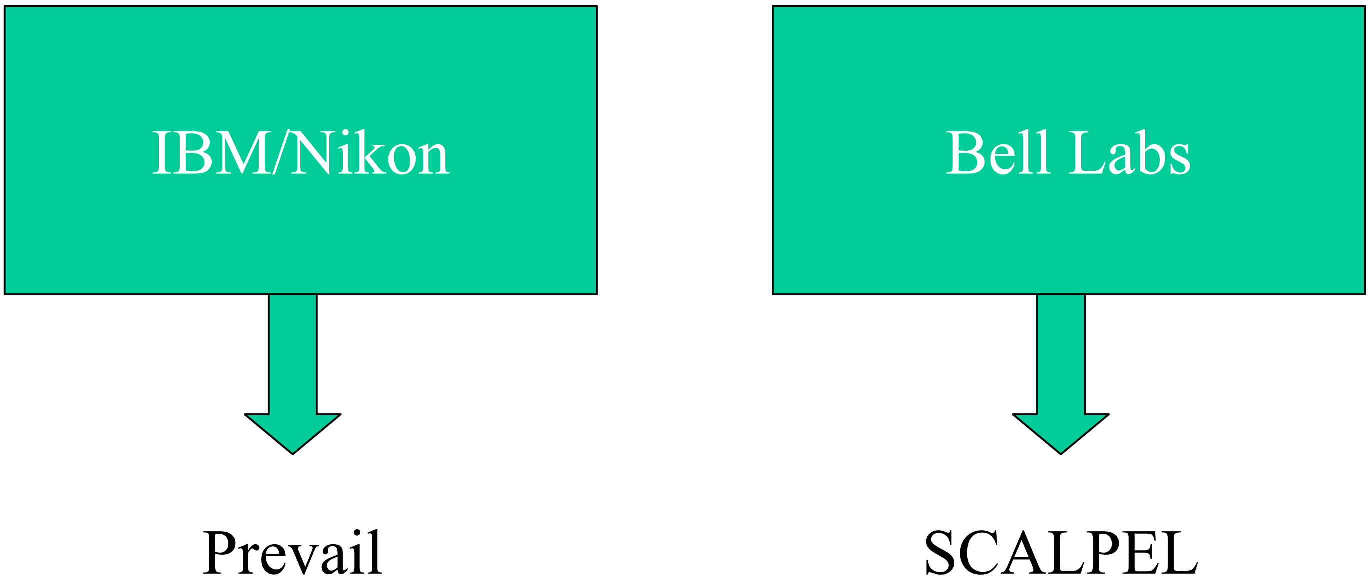
Examples IBM VS6, Leica VB series, EBPG, Jeol JBX

- Beam is deflected in a vector fashion with one or more deflection coils to fill in the shape of interest. Fill in can be basket weave, spiral, or raster.
- Advantages: Speed for sparse patterns, accuracy.
- Disadvantages: Some non-periodic errors are difficult to correct.

System Architecture

Beam Deflection – E-Beam Projection

Subject of Future Lecture



System Architecture

Typical System components

Source

Electrostatic lens

Magnetic lens

Deflector

Blanker

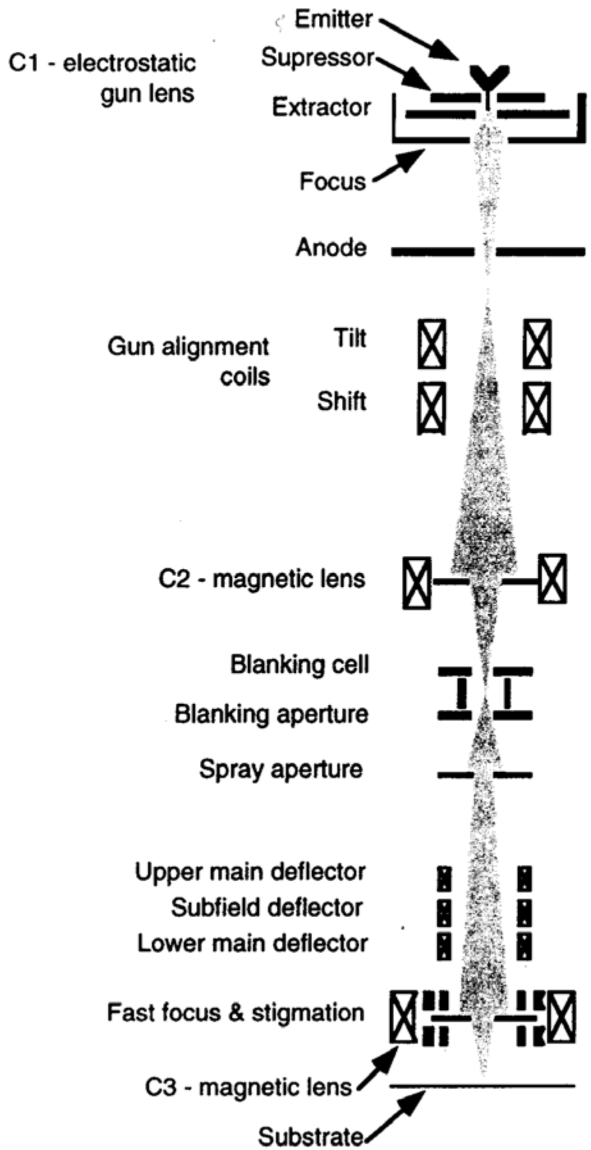
Height Sensor

Laser Interferometers

Vacuum system

Pattern Generator

Electron Optical Layout for the Leica VB6



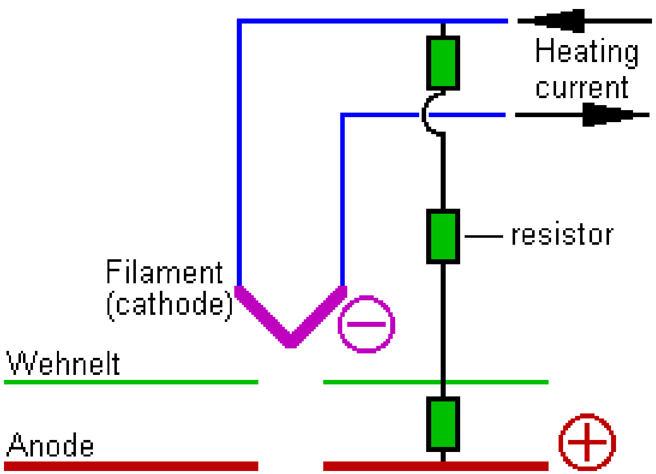
Source

- Tungsten
- LaB_6
- Thermal Field Emmiter (Schottky)
- Cold Field Emmiter

Electron emission, Is (amps/cm2), as a function of the absolute temperature, T, of a

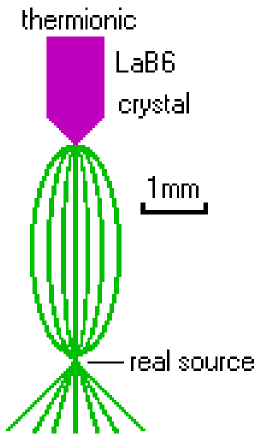
thermionic emitter is given by Richardson's equation:

$$I_s = AT^2e^{-(B/T)}$$

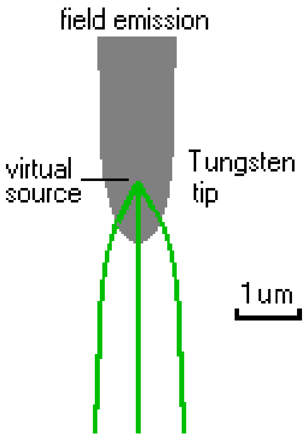


where A and B are constants that are determined empirically

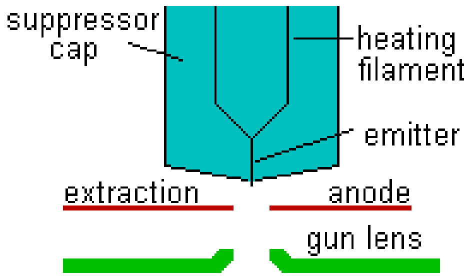
Electron Optics Basics – Sources LaB6



Electron Optics Basics – Sources FE



Electron Optics Basics – Sources TFE



System Architecture

Sources

Source

- Tungsten
- LaB_6
- Thermal Field Emmiter (Schottky)
- Cold Field Emmiter (Not normally used for Lithography)

System Architecture

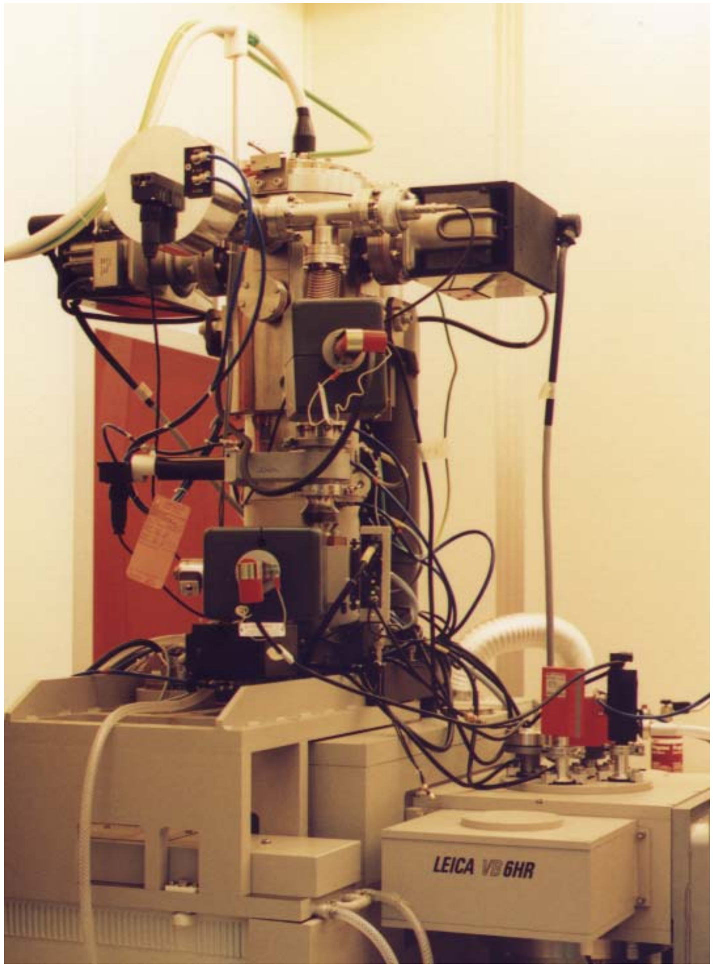
Source Characteristics

Source Type	Brightness [amp/cm2/str]	Source Size	Energy Spread	Vacuum Required (Torr)
Tungeston	10^5	25um	2-3eV	10^{-6}
LaB_6	10^6	10um	2-3eV	10^{-8}
TFE	10^8	25nm	0.9eV	10^{-9}
Cold FE	10^9	5nm	0.22eV	10^{-10}

System Architecture

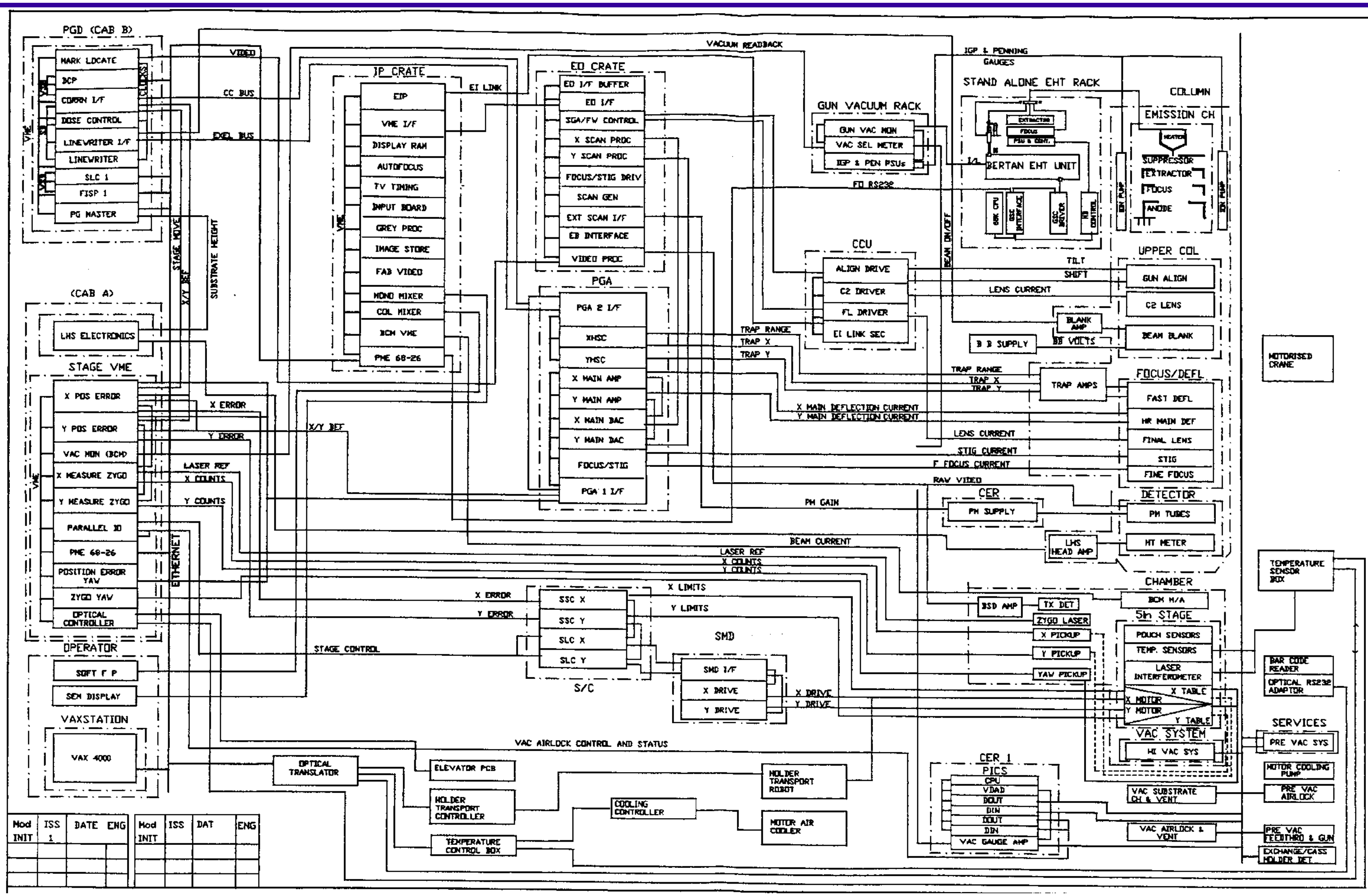
Nanowriter system specifications

- Column, Stage, and Ancillary Hardware based on Leica VB6-HR
- Pattern Generator, Data Path Developed at Berkeley Lab
- Beam Voltage 20-100KV
- Beam Size 5-10nm$\Rightarrow$5-8nm
- Deflection Rate 25MHz
- Resolution 16 Bit
- Interferometer λ/1024
- Wafer Size 75-200mm
- Electron Detection Backscattered and Transmission



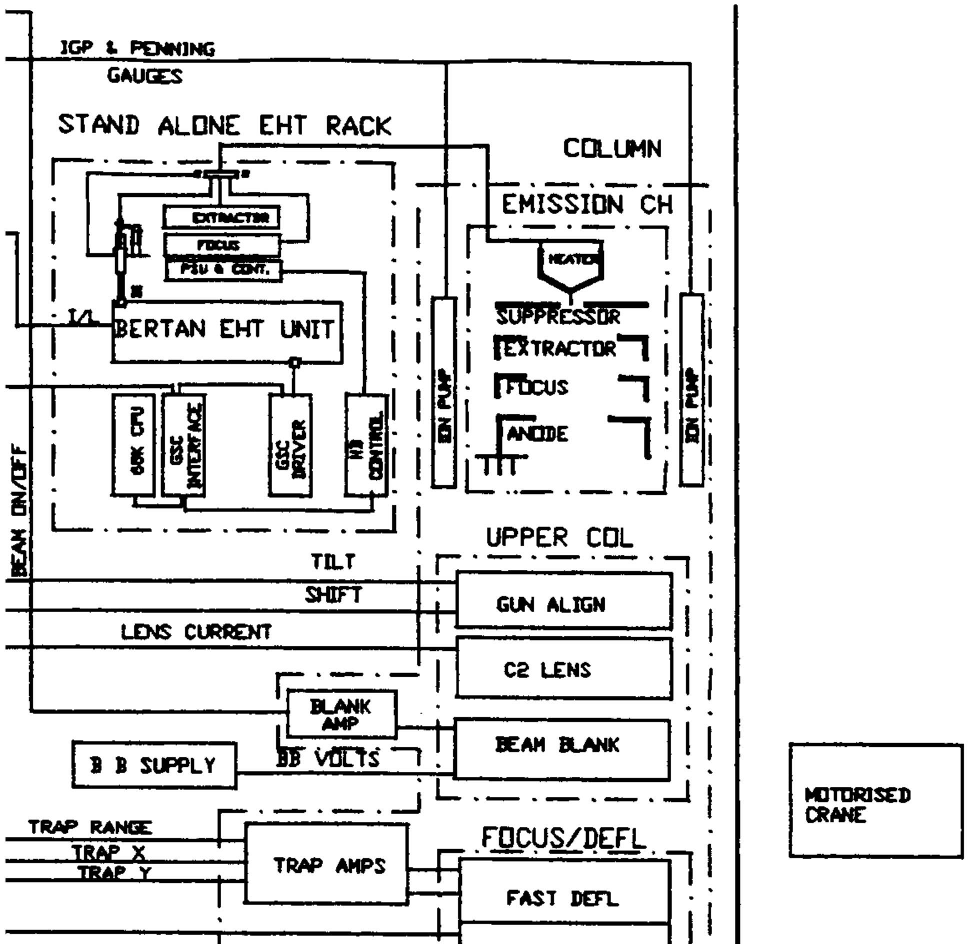
System Architecture

Vector Beam Block Diagram



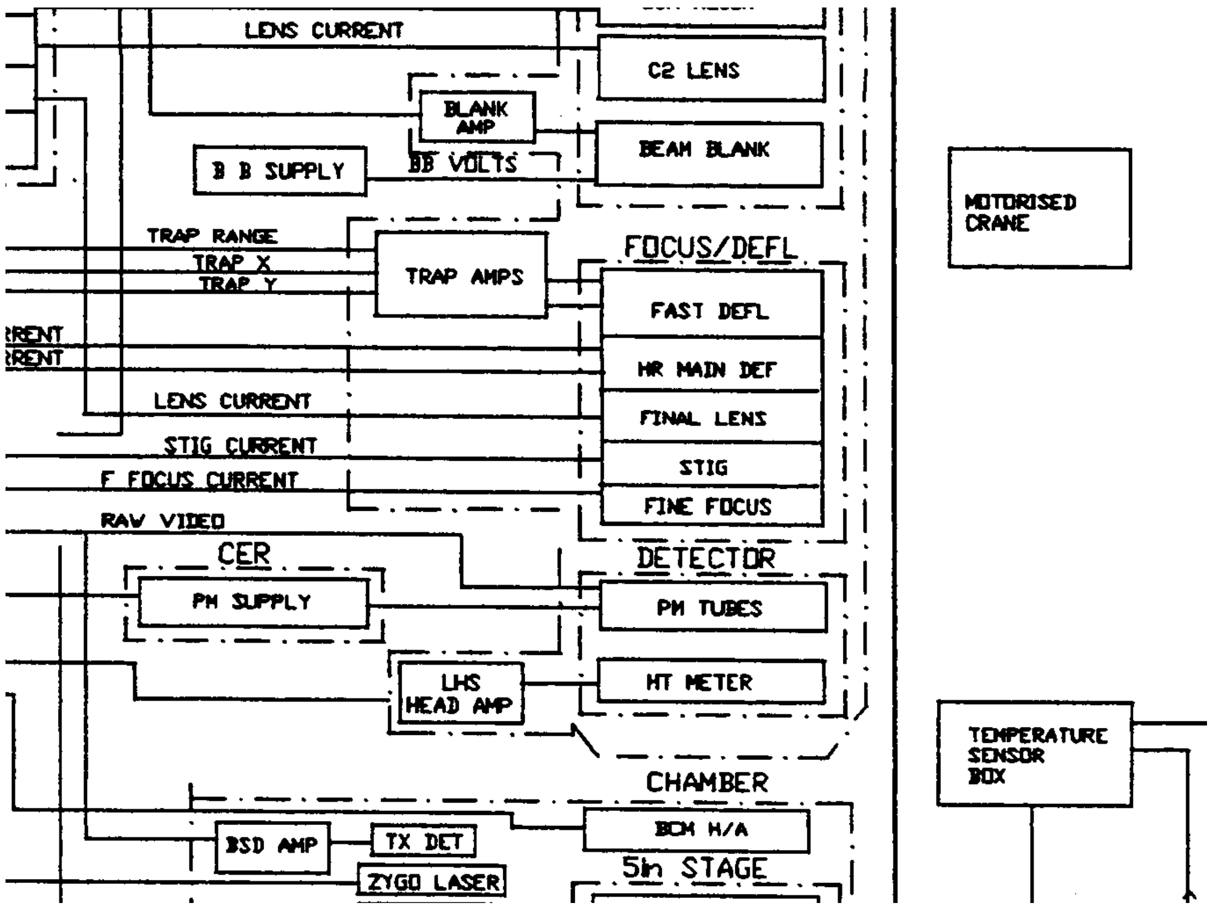
System Architecture

Gun and deflection



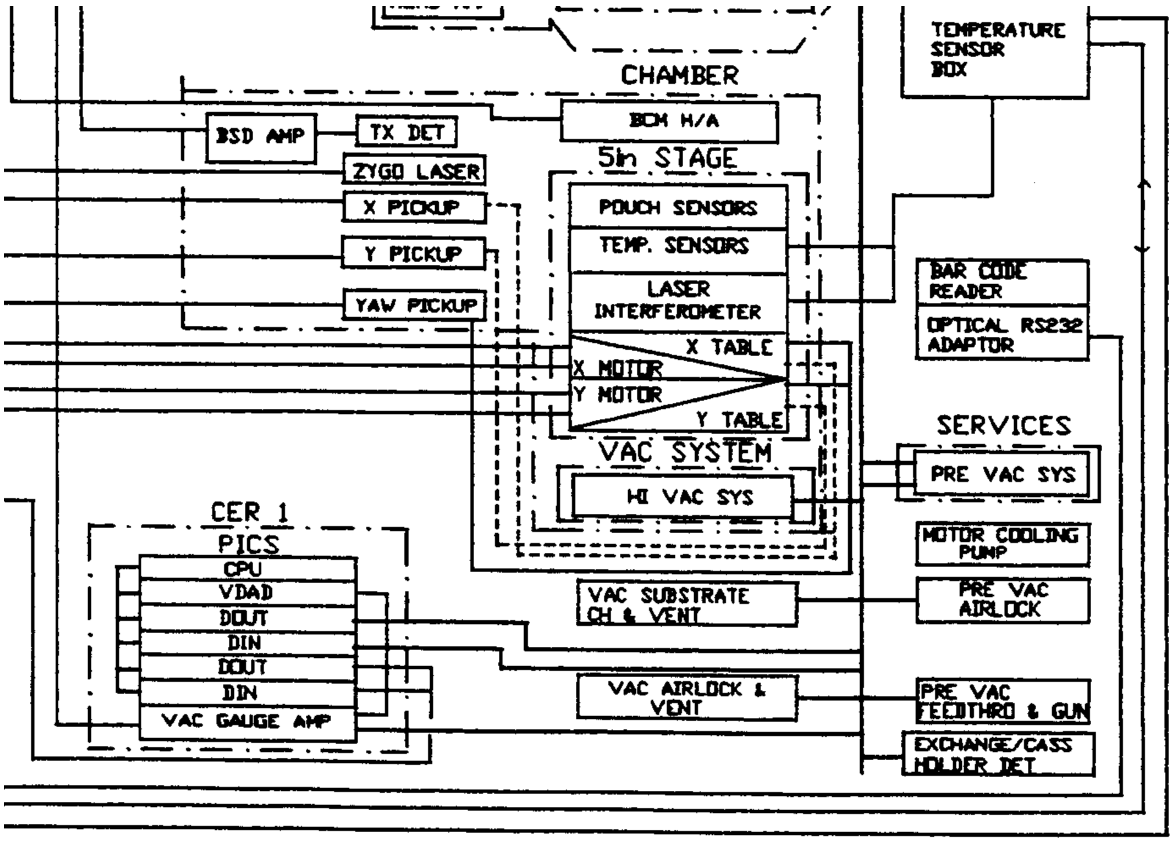
System Architecture

Deflection



System Architecture

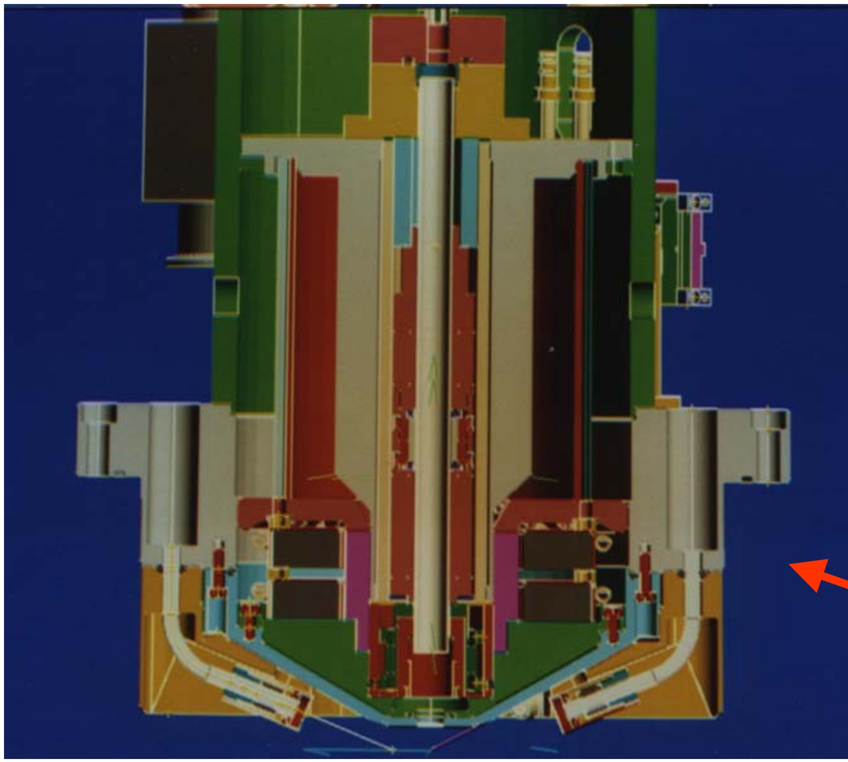
Chamber

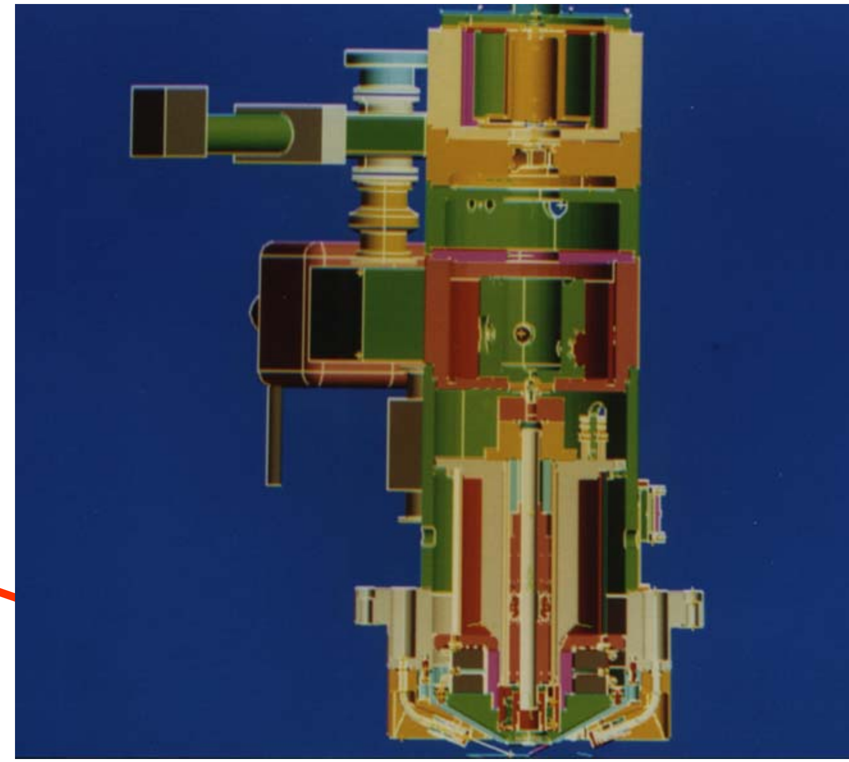


System Architecture

Column

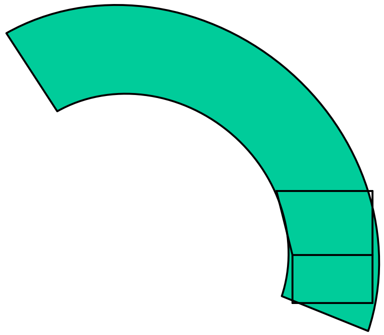
Gun





Wafer

LBNL Digital Pattern Generator for curved structures



How to draw smooth curved shapes?

Typical PGs will require rectangles, and trapezoids only.

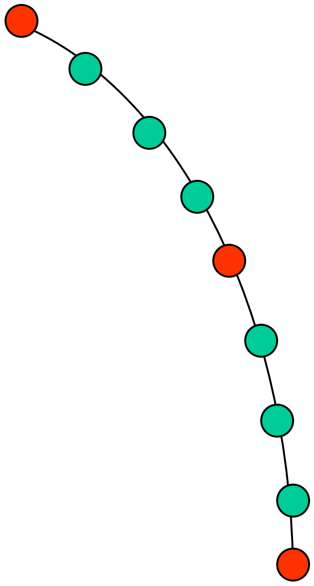
Equation to generate exposure coordinates

$$X(k) = a_0 + a_1 k + a_2 k^2$$

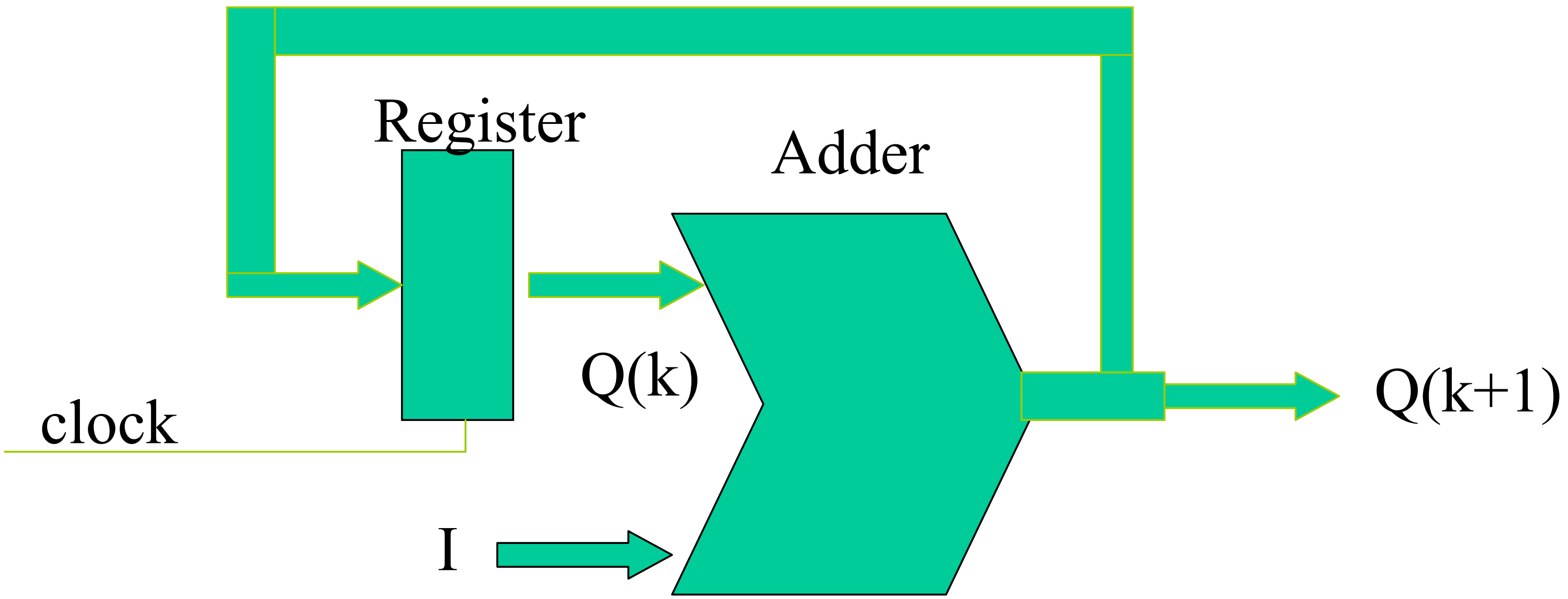
$$Y(k) = b_0 + b_1 k + b_2 k^2$$

We can always find the 6 cooefficients a_0 a_1 a_2 b_0 b_1 b_2

That pass through three distinct points.

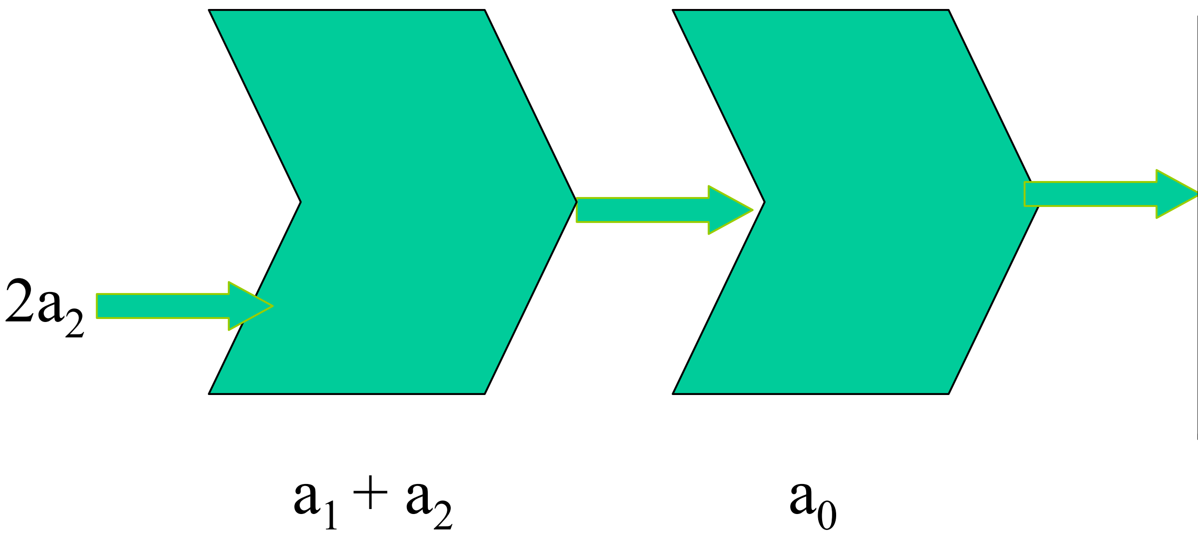


Digital Accumulator = Adder + Register



$$Q(k+1) = Q(k) + I$$

Two accumulators produce quadratic function



K	Ac1	Ac2
0	a0	a1+a2
1	a0+a1+a2	a1+3A2
2	a0+2a1+4a2	a1+5a2
3	a0+3a1+9a2	a1+7a2

$$X(k) = a_0 + a_1 k + + a_2 k^2$$

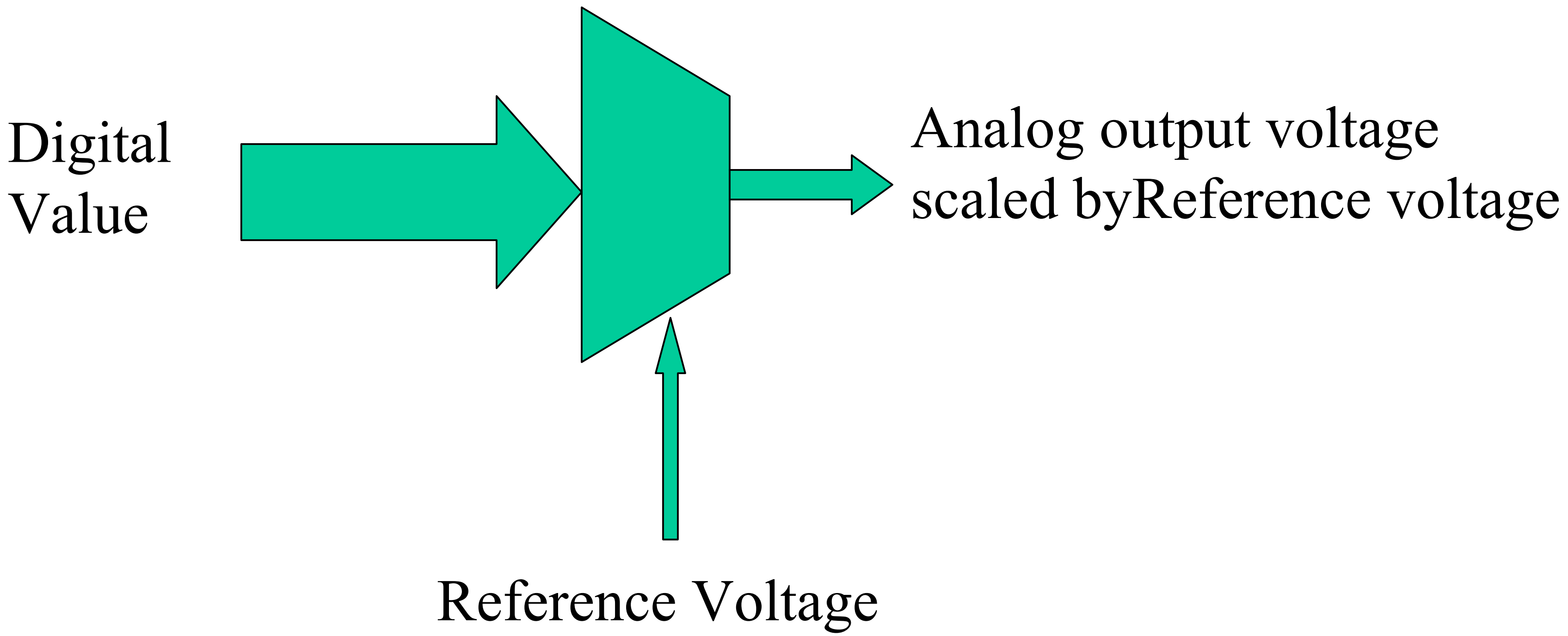
Scale and Rotation in Hardware

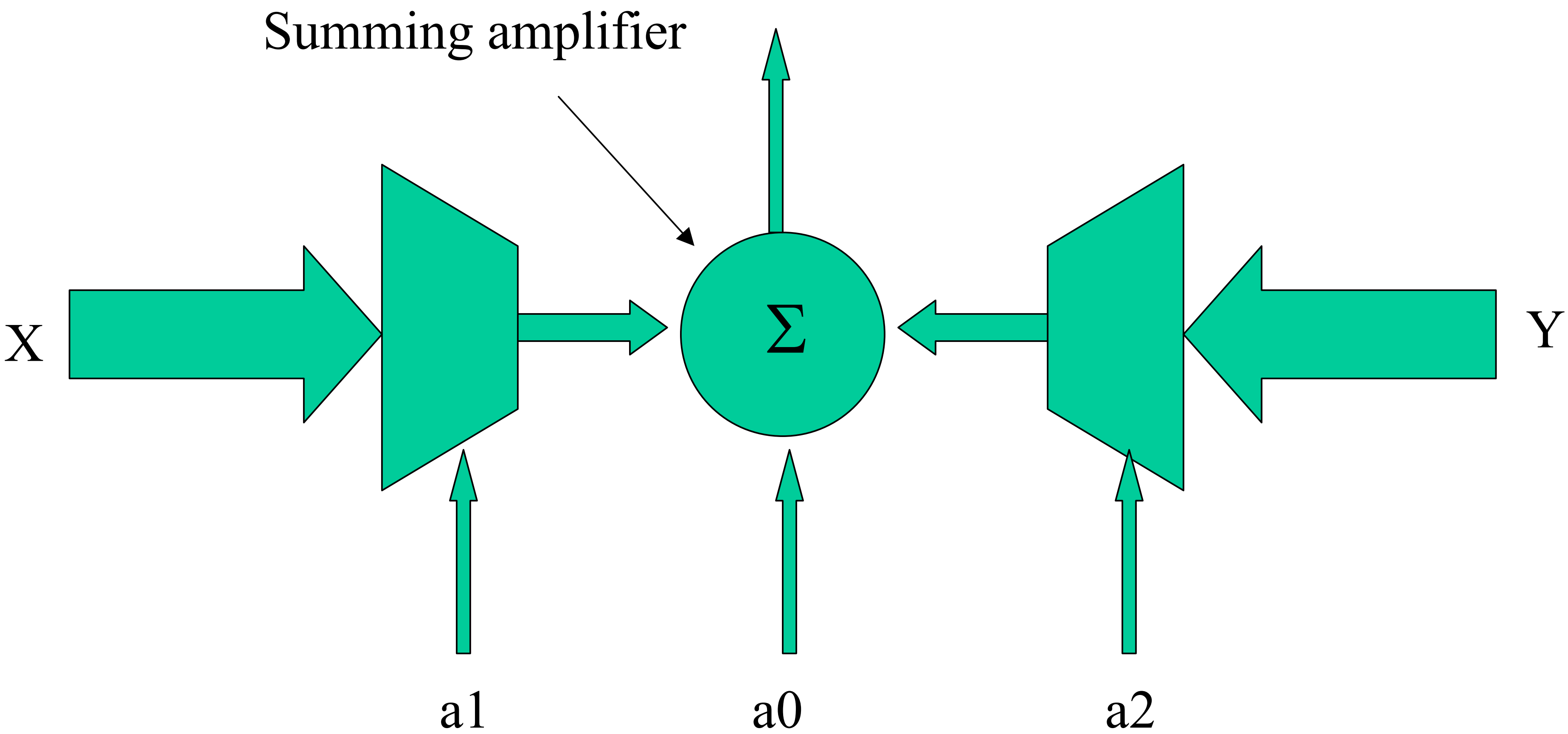
$$X = a0 + a1X + a2Y$$

$$X = b0 + b1X + b2Y$$

No rotation or scale a1=1, a2=0, b1=1 b2=0
In general this is not true!

Multiplying Digital Analog Converter (DAC)




Summing amplifier
X
Σ
Y
a1
a0
a2

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